Construction of the LTP Optical Bench Interferometer

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LISA Symposium

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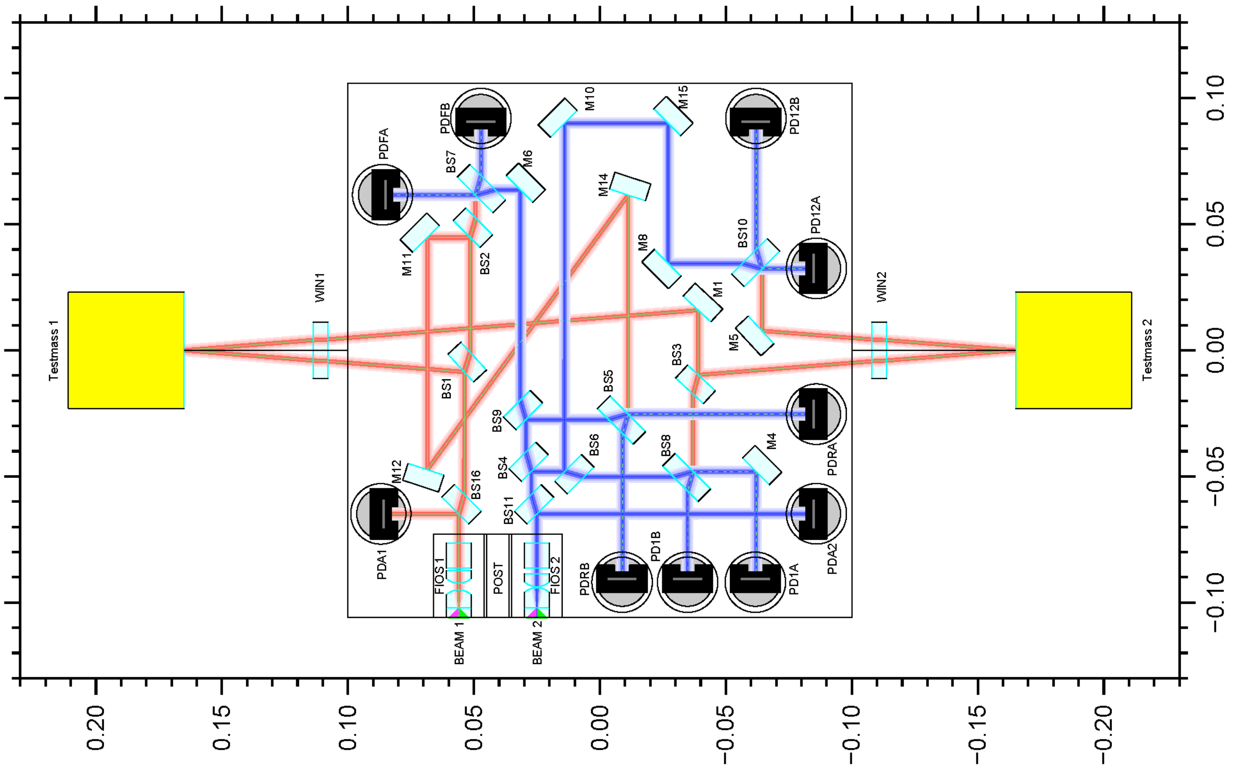
Outline

- LTP optical bench overview
- Engineering model to flight model
  - Concentrate on the changes
- Fibre Injectors
  - Bringing light from optical fibres onto the optical bench
- Positioning optical beams
  - Tolerances
  - How to do it

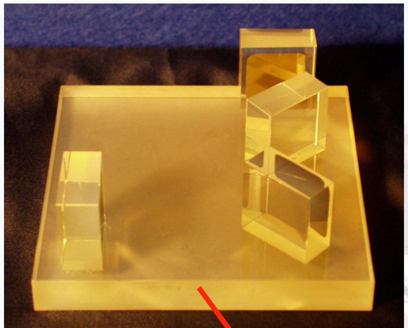
LTP Optical layout

- The purpose of the optical bench is to provide an optical measurement of the displacement of the two inertial test masses
  - Sensitivity of order 10pm/rt(Hz)
  - The optical layout has two beams (of slightly different frequency) coming onto the bench, four recombinations and two test mass reflection points



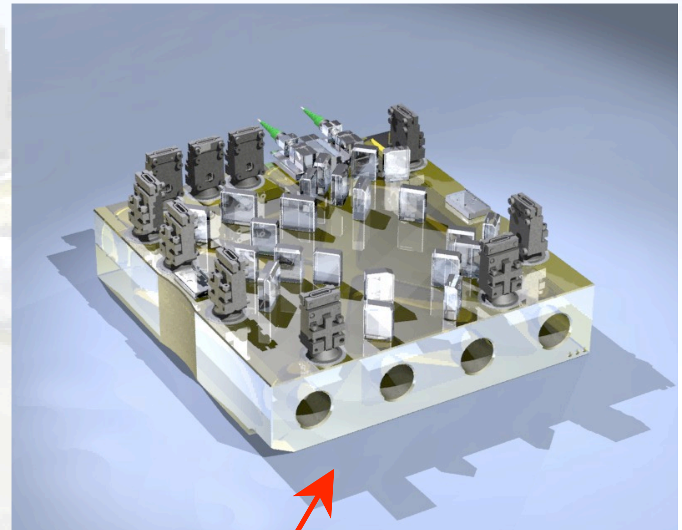
lipe Guzmán Cervantes, 23 Mar 2006

Historical progression of bonded OB’s

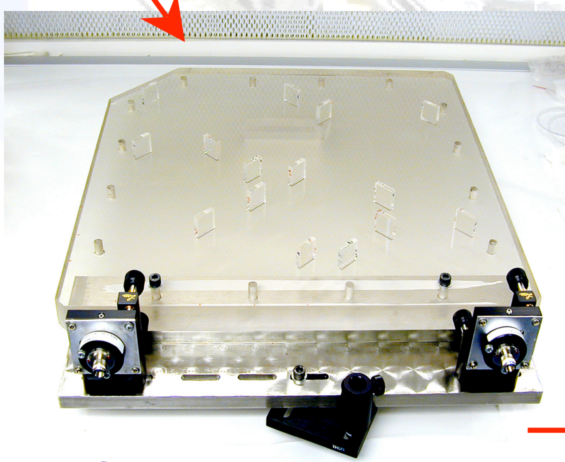


Test piece

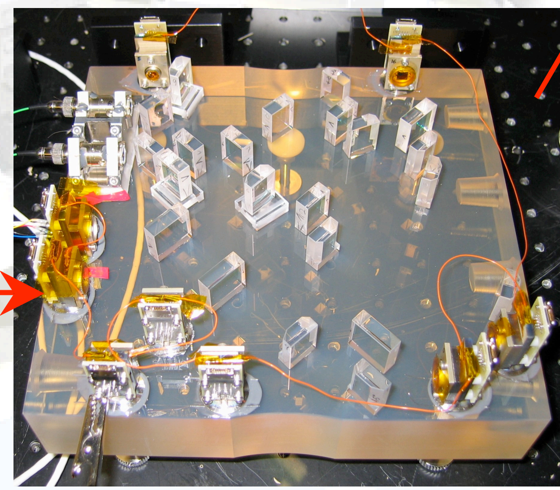
- In every case the critical components are fused silica and are hyroxy-catalysis bonded to a low expansion baseplate of ULE or Zerodur



Flight model



Interferometry prototype



Engineering model

Rutherford Appleton Laboratory CLRC

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astrium

Contraves Space

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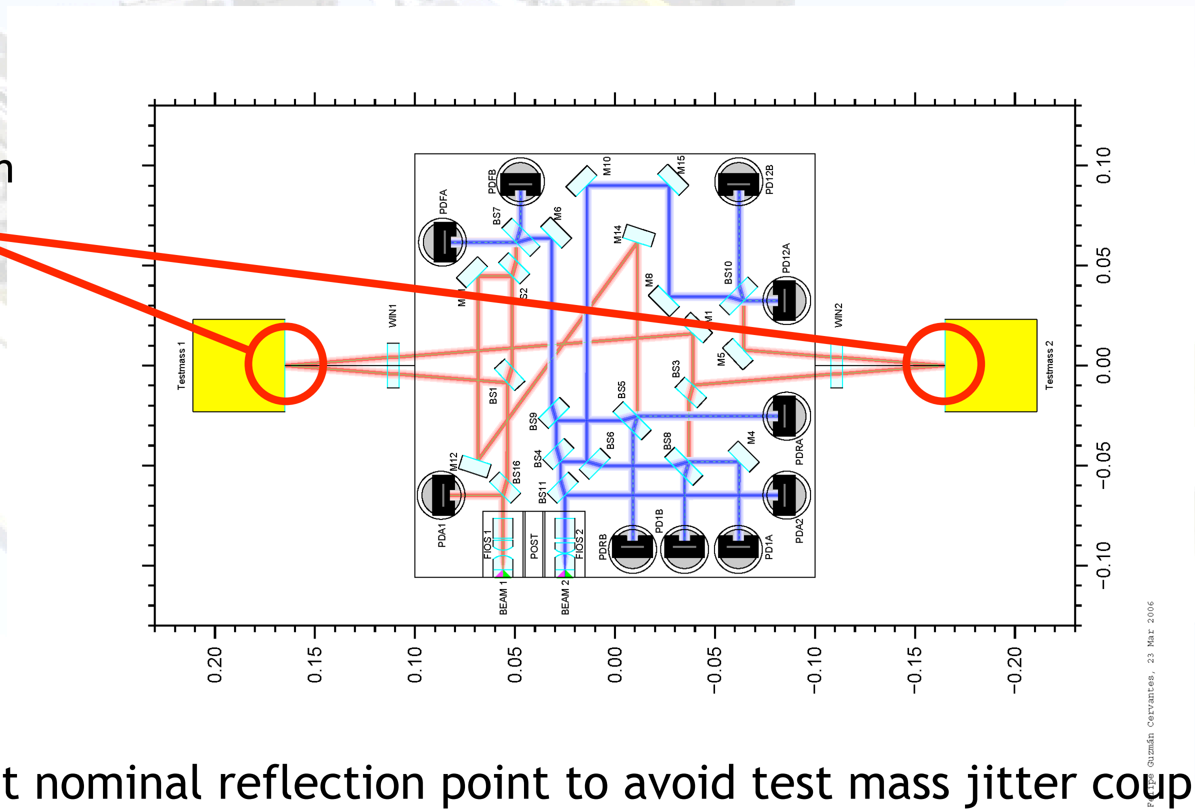
EM -> FM

- The LTP engineering model (EM) was constructed in RAL
- EM successfully tested at TNO and Hannover
  - Mechanical strength proven at TNO
  - Noise performance demonstrated at Hannover
  - Overall, demonstrated the advanced alignment and construction techniques required for an interferometer of this complexity
- Flight model is essentially same physical layout as the engineering model but some crucial differences
  - Fibre injectors need major development
  - Optical alignment tolerances need to be tightened significantly
  - Lightweighting required
  - FM has to operate with free floating test masses in the optical chain

Optical beam position at TM’s

- Challenging requirement is to hit a virtual point in space to within ±25 _m

Test mass nominal beam reflection points



- Has to hit nominal reflection point to avoid test mass jitter coupling into measurement
  - Can’t drive TM to ifo ‘sweet spot’ as TM control electronics too noisy away from electrode housing ‘sweet spot’

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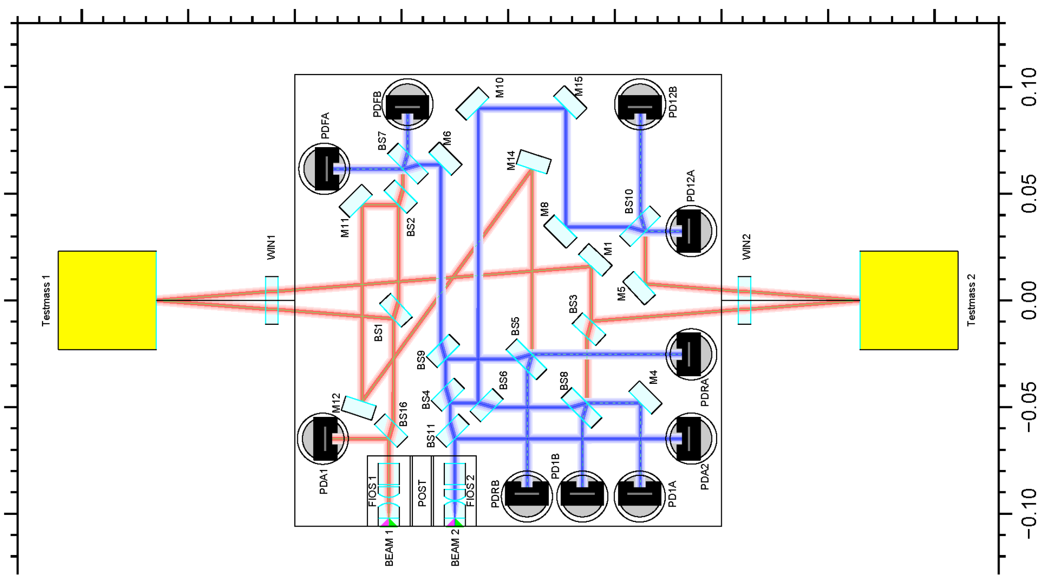
Fibre injectors - some history

- The "fibre injectors" match the optical beam from the optical fibre onto the optical bench
  - Require good output beam quality and good long term pointing stability
- The "EM" OBI was far from being a true EM
- For the EM build commercial Fibre Injectors (FIOSs) were adopted – due to time and cost constraints
- For the FM we need to move to
  - an injector capable of more precise alignment than the EM versions
  - a design that is magnetically (and otherwise) clean
  - a design that can be satisfactorily space qualified
- Lacking time and resources to maintain multiple development strands, the UGL goal from the start has been to focus on an essentially monolithic fused silica FIOS design

Fibre injector assembly – optical design

- Significant design drivers are:
  - Optimisation of the beam matching (size, curvature) at the critical OBI interference points
    - PD12A/B and PD1A/B
    - Different distances from the fibre injectors to the photodiodes
  - Minimisation of the beam size at the proof masses

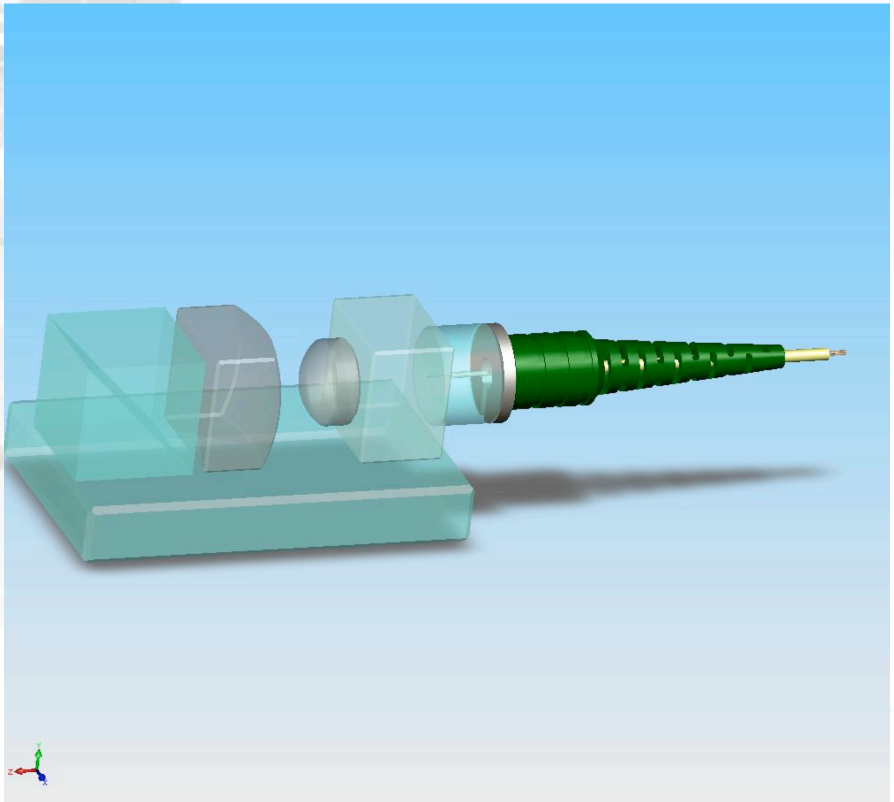


	Revised layout (S2-UGL-TN-3016)	
	Beam 1	**Beam 2**
PDA1/2	79.72	160.1
PDFB	221.3	245.4
PDFA	223.9	248.0
PD1B	548.0	189.6
PD1A	569.2	210.8
PDRA	571.9	213.6
PDRB	567.7	209.4
PD12A	738.9	380.6
PD12B	780.8	422.5

All lengths in mm

Fiber injectors - optical design

- Require aspheric lenses to minimise spherical aberation
  - See modelling results
- Twin lens assembly
  - Interlens spacing available for adjustment purposes
  - Easier manufacturability of lenses
- The interference quality can be optimised by building the two fibre injectors with different fibre to lens interlens spacings
- Same curvature for all lenses: R=7.45mm



Modelling and Tolerancing

- Fibre injector modelled in Zemax to achieve optimal design and find required component tolerances

FIOS 1 design

FIOS 2 design

- Twin lens design also allows compensation of manufacturing tolerances of the lenses and fixed spacer
  - For a +/- 40 micron manufacturing error in lens length satisfactory absolute beam sizes and curvatures can be recovered by adjustment of the inter-lens spacing over a 400 micron range
  - Adjustment precision required is (a not too demanding) +/- 20 microns
- More significant is the effect of an error in knowledge of the fibre exit waist size
  - Much effort has been invested in development of beam size metrology
  - Current measurements are now well understood, but a final check of effective beam size when the embedded fibre is bonded onto a fused silica spacer remains to be done

ZEMAX optical modelling results

- Assuming a beam waist at the fibre output of 4 microns, for **FIOS 1** the spacer length between the fibre exit and the first lens curved surface is **6.250 mm** and the interlens gap to **4.619 mm**
- A suitably matching design for **FIOS 2** is obtained by adjusting the spacer length between the fibre exit and the first lens curved surface to **6.500 mm** and also adjusting the interlens gap to **3.353 mm**
- This positions the beam waist between the test masses and optimises the interference quality at the PD12A/B photodiodes

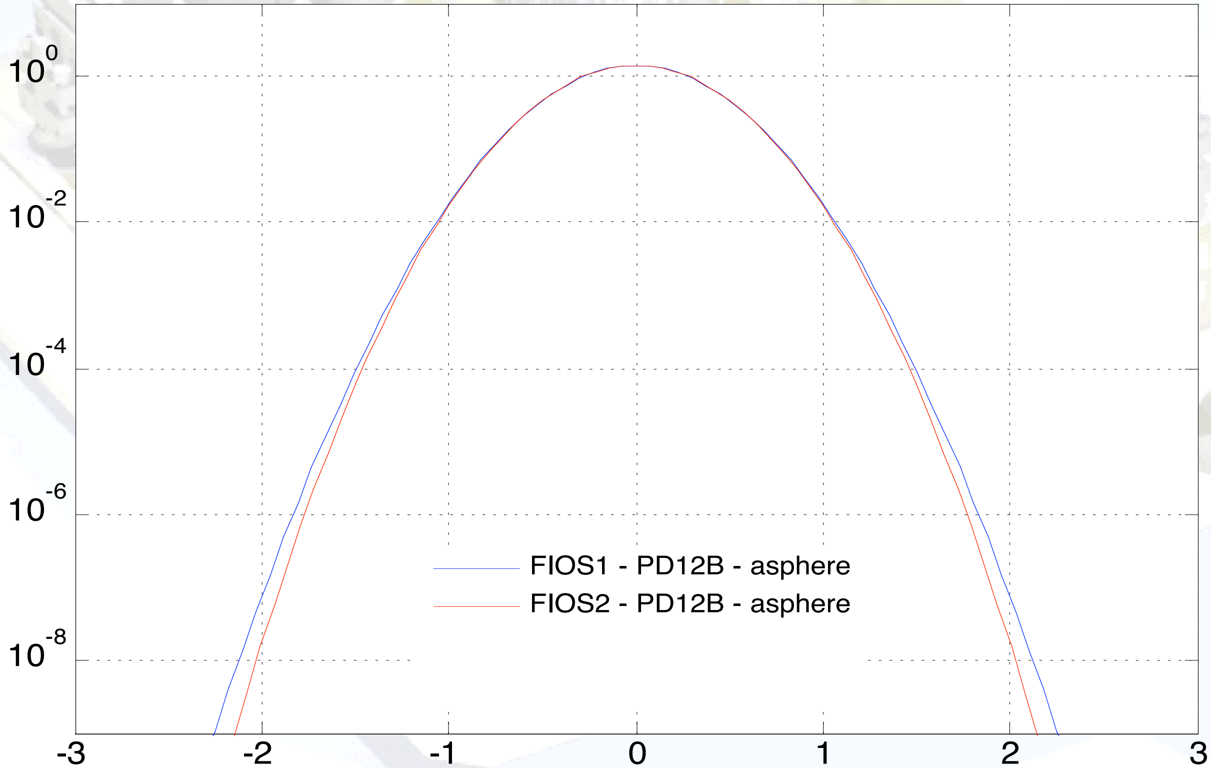
Beam parameters

- These example designs yield essentially perfect matching between the interfering beams at the x1, x1-x2 and reference interference points
- As expected, the interfering beams at the frequency noise recombination photodiodes are not perfectly matched
  - beam size matching is essentially perfect
  - curvature mismatch will limit fringe visibility to ~92%
- As a useful summary, the beam parameters at the main photodiodes (extracted from the data presented earlier) are shown in the table opposite

	Revised layout (S2-UGL-TN-3016)					
Photodiode	**ZEMAX surface**		**Beam radius (microns)**		**Beam curvature (metres)**	
	FIOS 1	**FIOS 2**	**FIOS 1**	**FIOS 2**	**FIOS 1**	**FIOS 2**
PDFB	16	19	654	656	- 8.2	8.1
PDFA	17	20	654	654	- 8.3	8.0
PD1B	24	12	650	651	11.3	11.3
PD1A	26	14	651	652	9.8	9.8
PDRA	27	15	652	652	9.7	9.7
PDRB	25	13	652	651	9.9	9.9
PD12A	29	21	669	669	5.0	5.0
PD12B	30	23	675	675	4.5	4.5

Typical beam size matching

- Typical results of modelling the FIOS
  - Results shown are for PD12_2 with nominal FIOS 1 and FIOS 2 designs



Typical beam wavefront matching

- Typical results of modelling the FIOS
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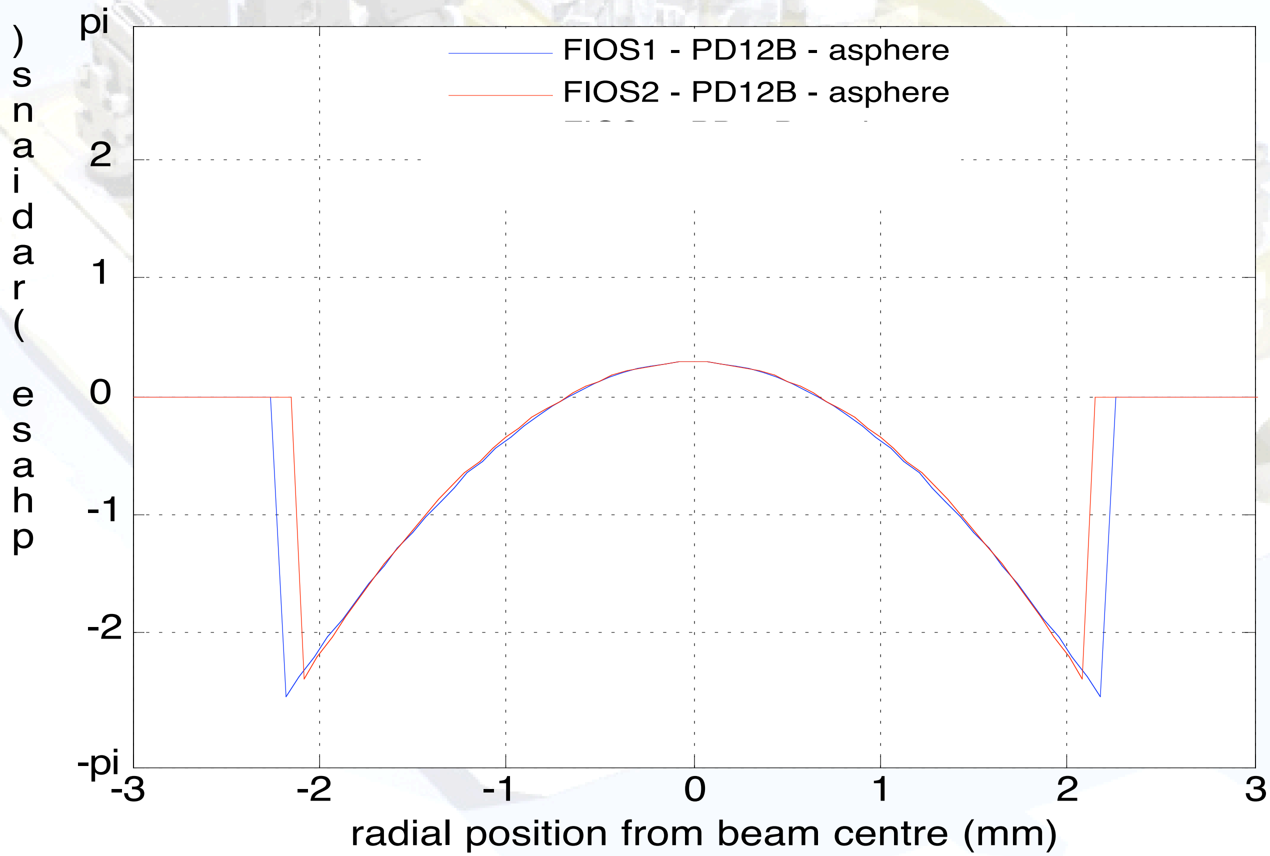
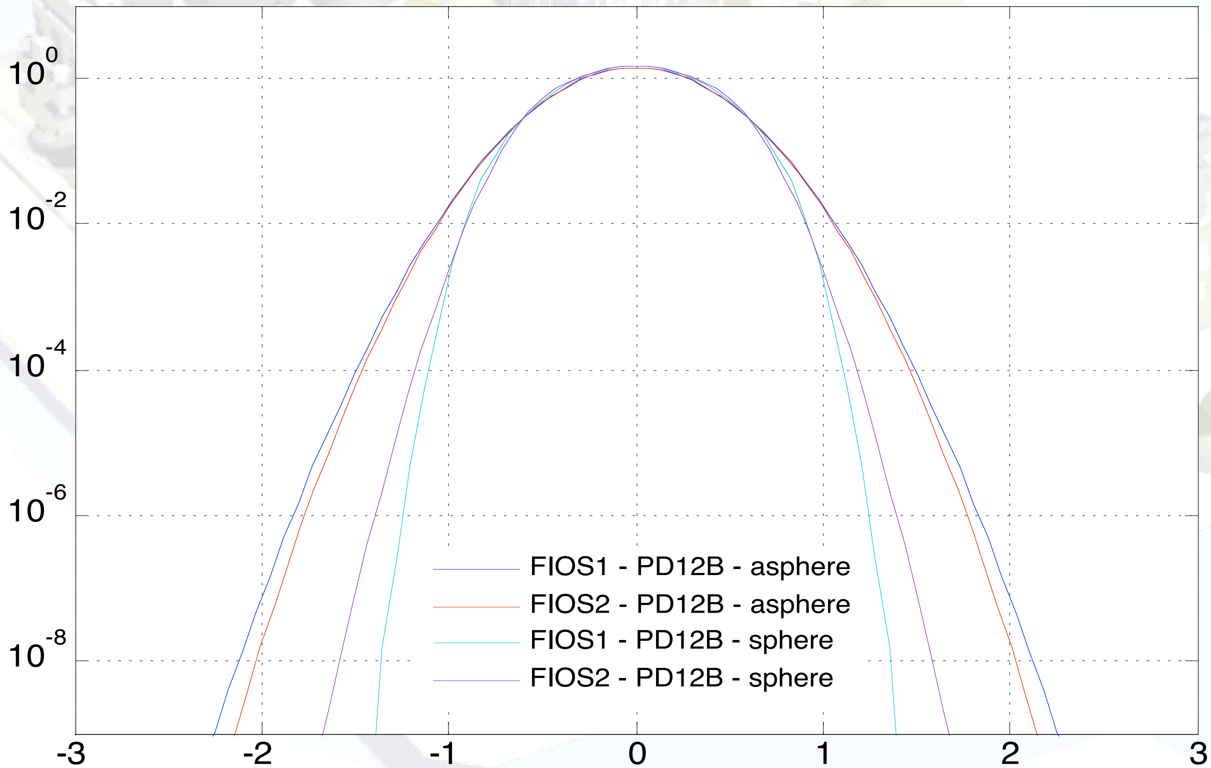


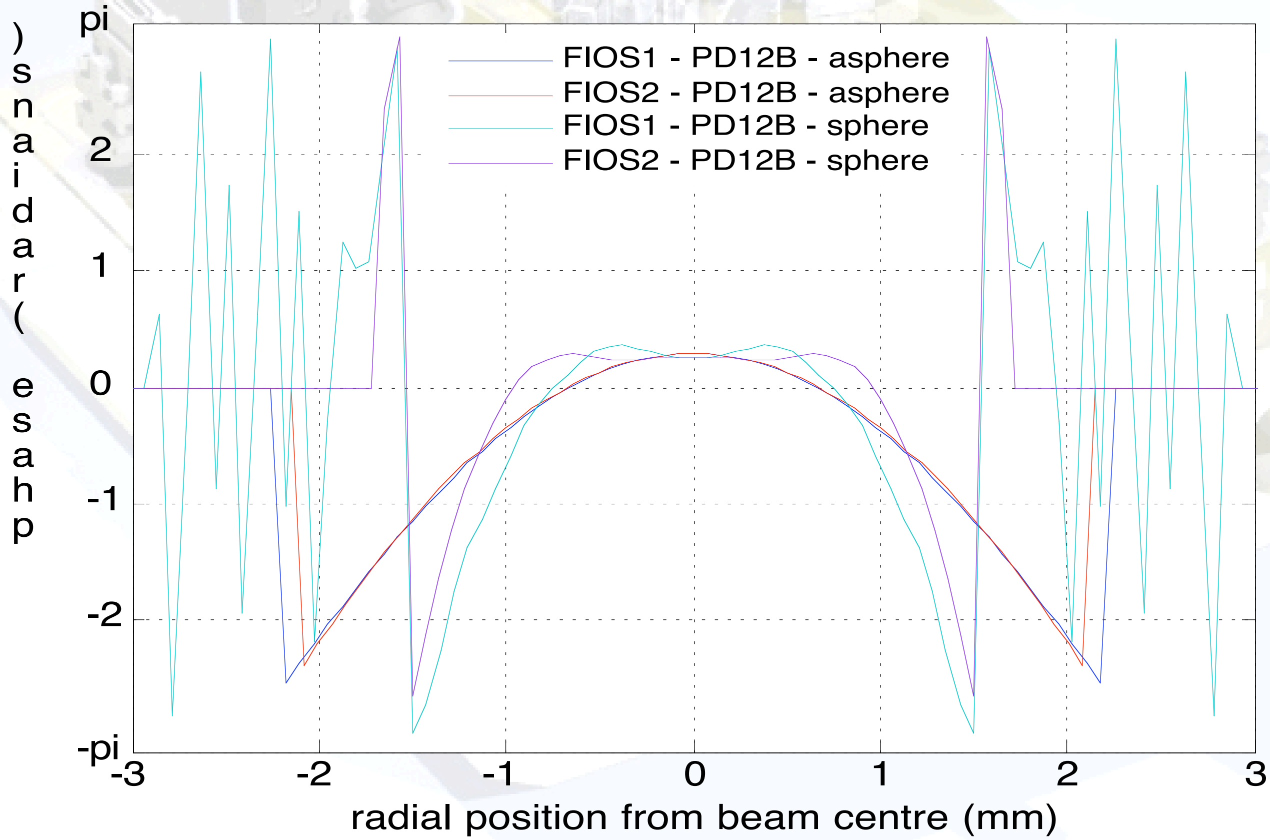
Beam size matching
spheric vs aspheric lenses

- Comparison of aspherically corrected FIOS and spherical lens design



Beam wavefronts matching spheric vs aspheric lenses

- Comparison of aspherically corrected FIOS and spherical lens design



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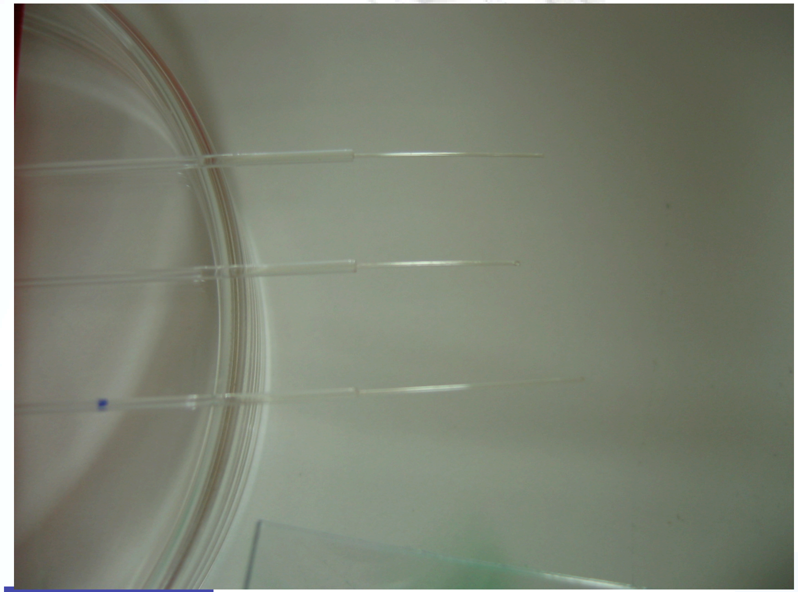
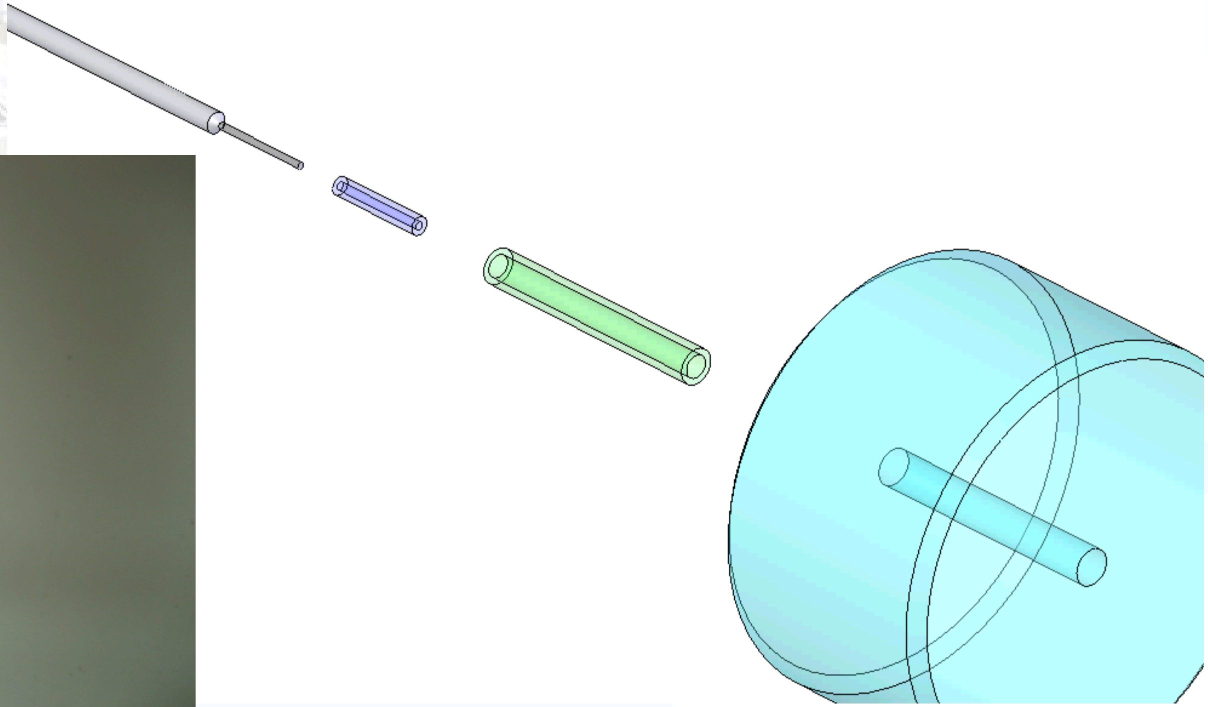
Fibre mounting strategy

- Fibre bonded into fused silica capillary tubing
- Fibre/capillary tube assembly bonded into hole in fused silica disk
- Disk face and fibre end polished flat for bonding to lens





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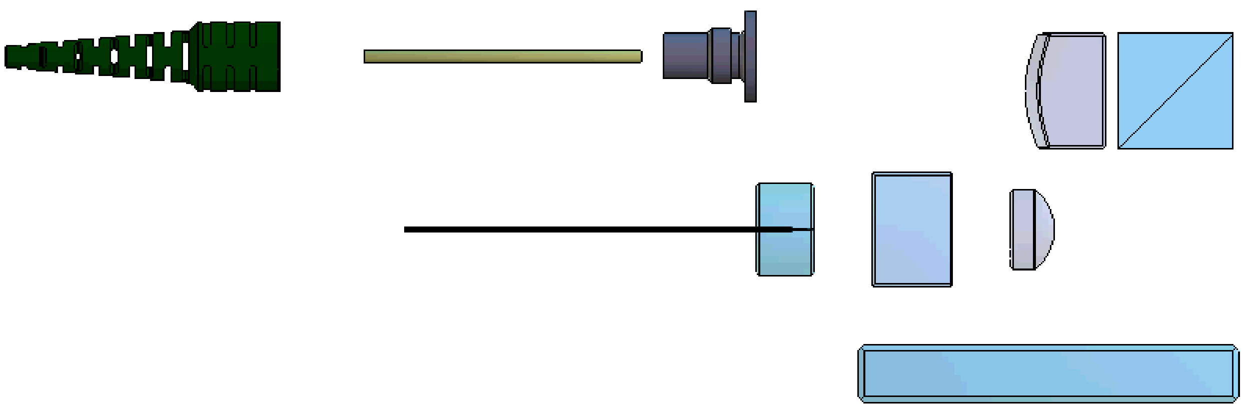
Complete FI design

- The second lens is positioned using an interferometric phase camera readout to ensure the beam parameters are as required



Optical beam position at TM's

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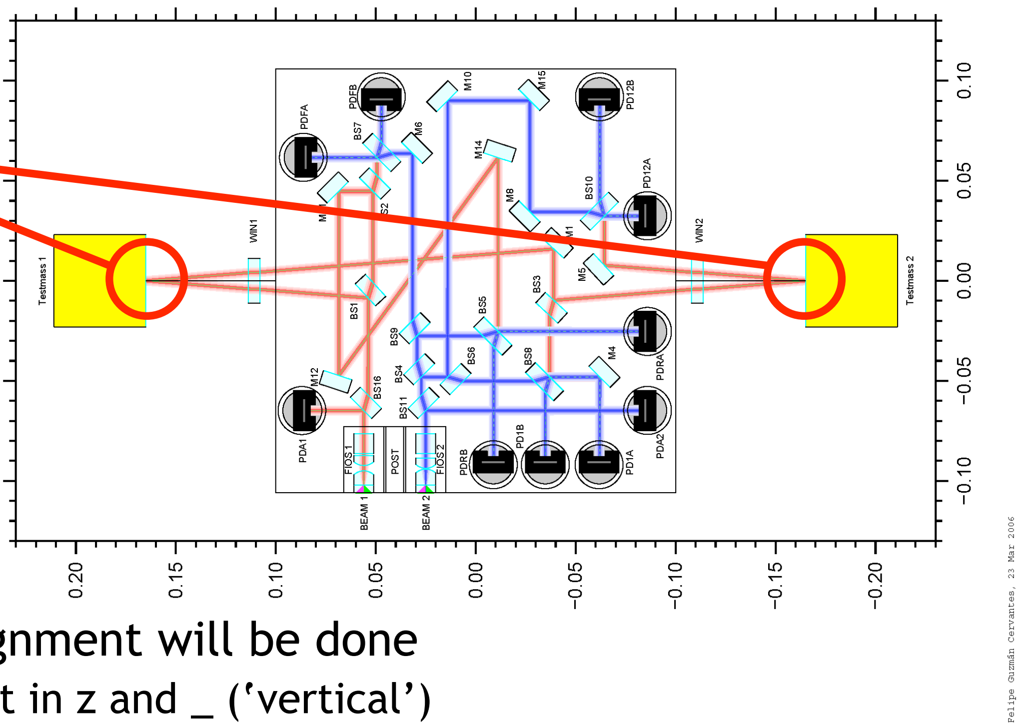
Test mass nominal beam reflection points



- How the alignment will be done
  - Alignment in z and _ ('vertical')
  - Alignment in y and _ ('horizontal')
  - Adjustment principle
  - Beam position and measurement with respect to OB baseplate

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Coordinate transfer

- The nominal beam centre at defined positions (relative to the OB baseplate) can be extracted from the optical modelling program, OptoCad
- These can be used in conjunction with the calibrated quadrant photodiode (CQPD) calibration data to place the photodiodes in the required positions
- The beam can then be aligned to the photodiodes
- The flow diagram opposite is taken from the alignment plan (S2-UGL-PL-3002)

Nominal beam position (in OBI reference frame) at two locations from optical model

⇩

Position baseplate within CMM measuring volume and measure location. Change CMM coordinate frame to the OBI frame.

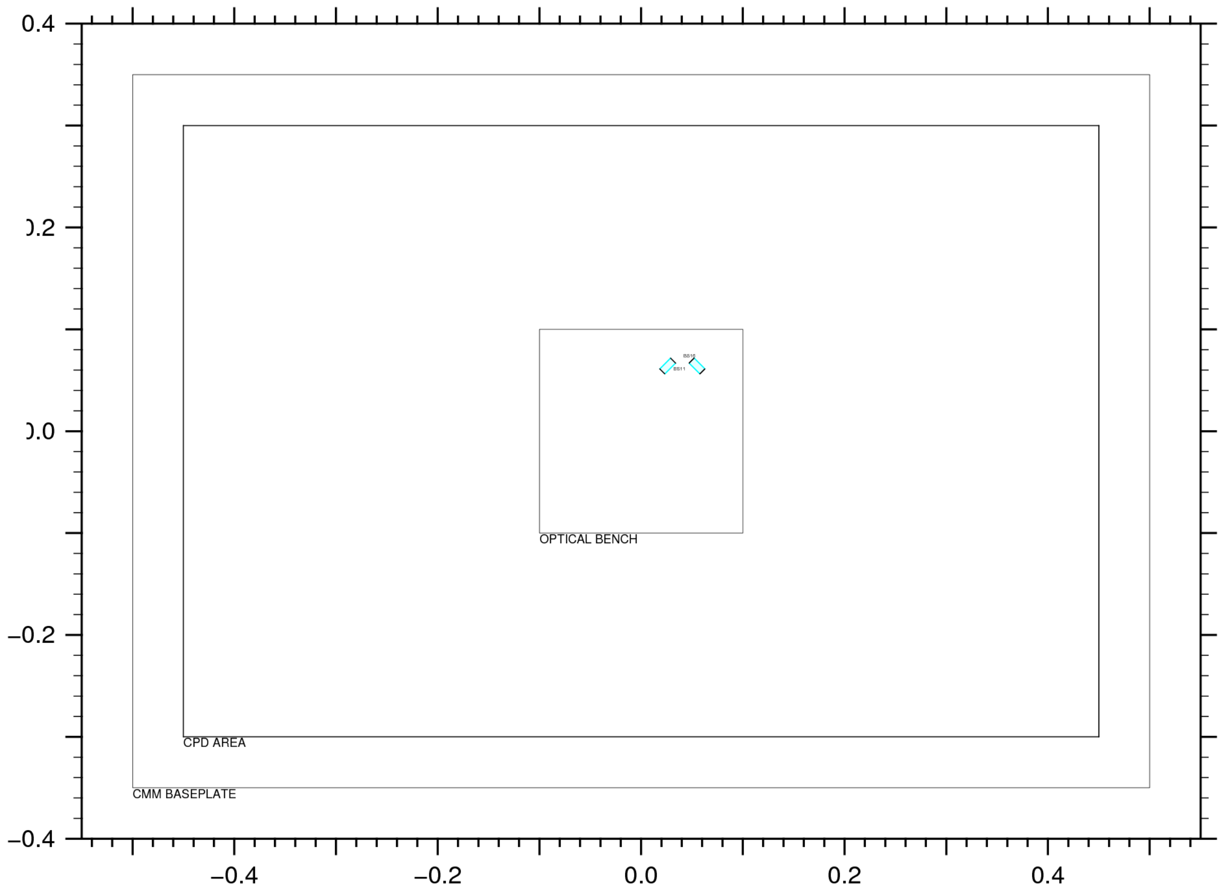
⇩

Position CQPDs relative to the baseplate using CMM such that their centres are at the nominal beam positions. These coordinates are calculated using offsets determined during calibrations (see Section 2)

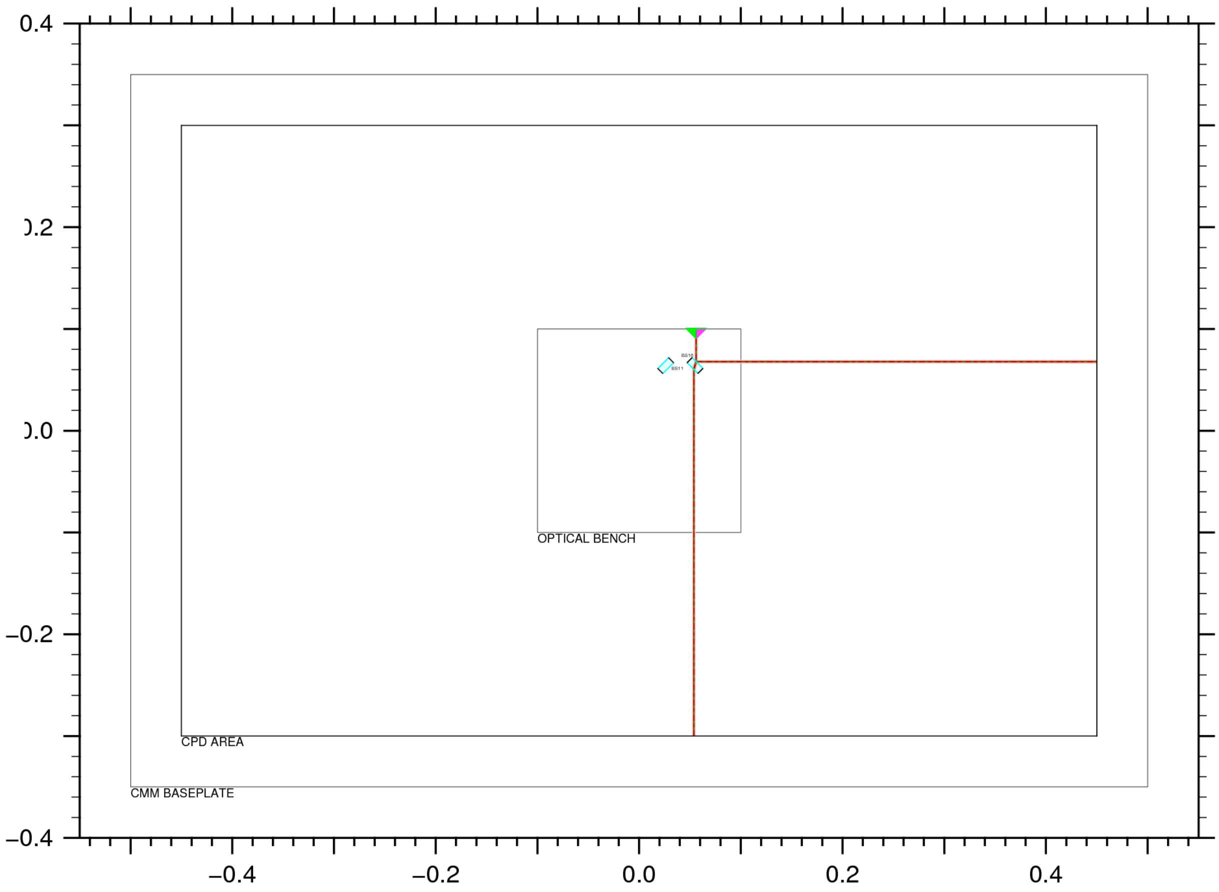
⇩

Provided the CQPDs remain fixed relative to the baseplate then the beam can be aligned to them (using the adjustable bonding technique) and the adjustable component bonded ensuring the beam is at its nominal geometry.

Building up the OB

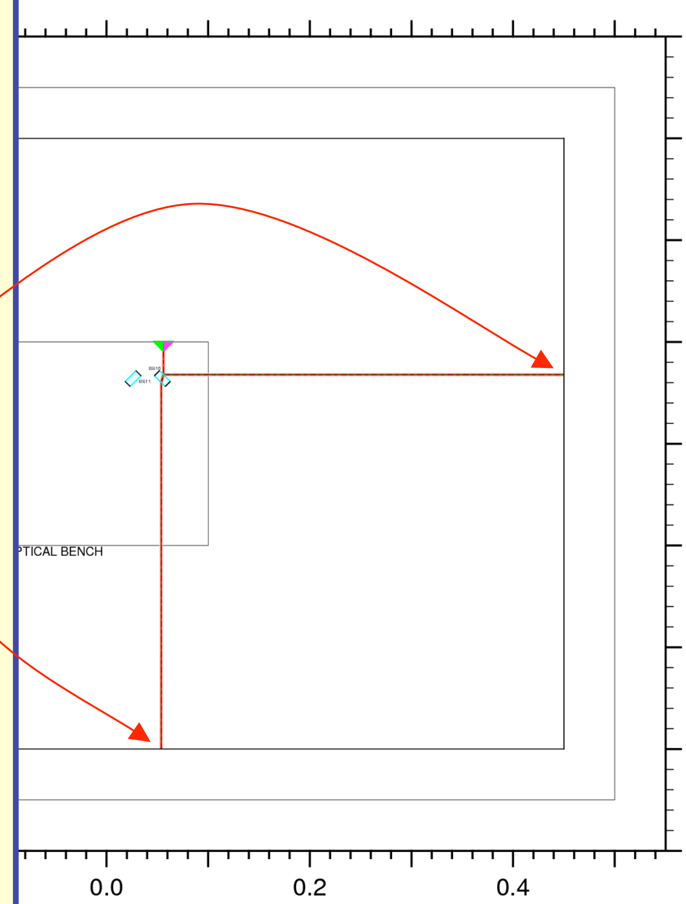


Building up the OB



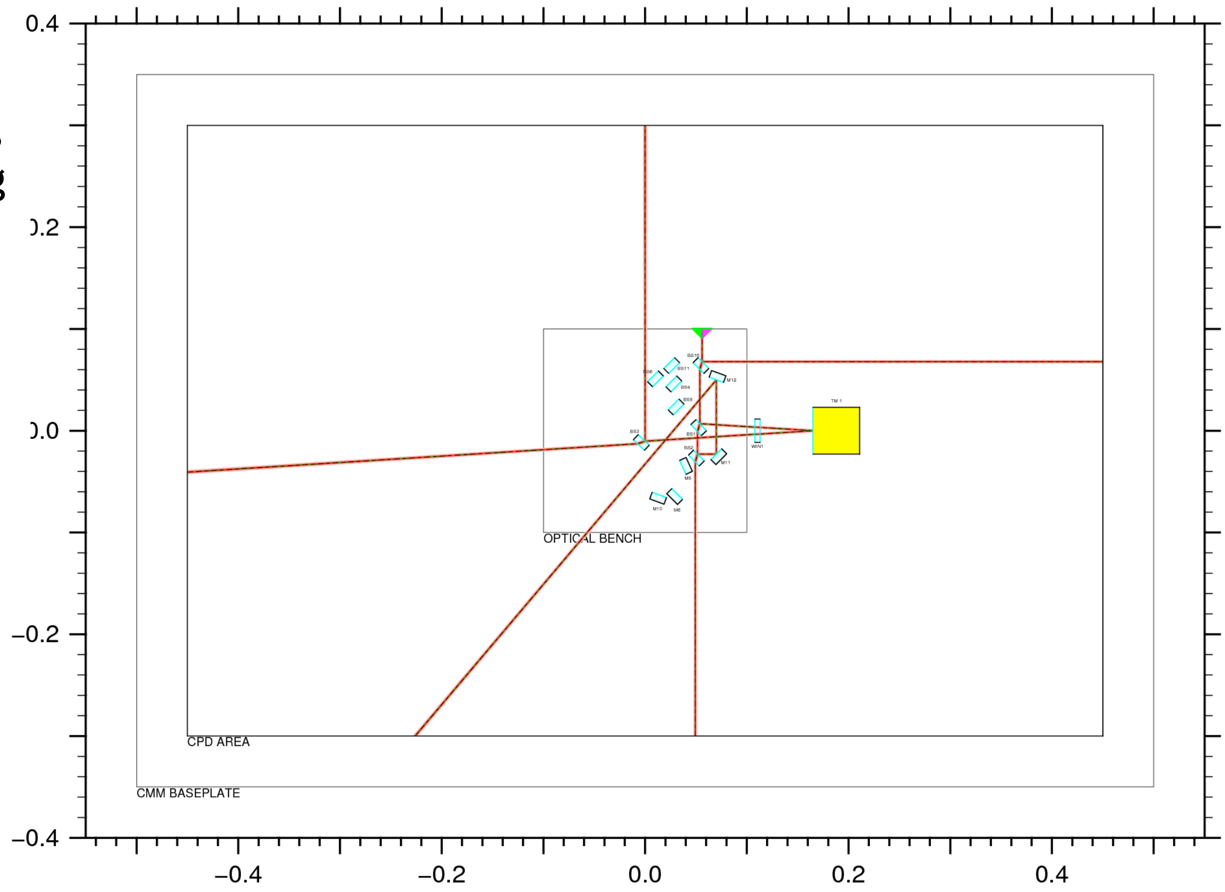
Building up the OB

```
This is OptoCad (Version 0.80h) by Roland Schilling.
All rights reserved. ABSOLUTELY NO WARRANTY!

Input of optical component data from file 1-fi-ref.oc

Beam # 1:
     x2[m]       y2[m]     an2[deg] label
 56.00000E-3  100.0000E-3         0.0 @ beam start
 56.00000E-3  67.85700E-3  45.00000E+0 # BS16
 53.81601E-3  60.14149E-3 -150.8049E+0 + BS16
 53.81601E-3 -300.0000E-3  180.0000E+0 # bottom border

     x2[m]       y2[m]     an2[deg] label
 56.00000E-3  67.85700E-3  45.00000E+0 # BS16
 450.0000E-3  67.85700E-3         0.0 # right border

Beam # 1:
     x2[m]       y2[m]     an2[deg] label
 56.00000E-3  100.0000E-3         0.0 @ beam start
 56.00000E-3  67.85700E-3  45.00000E+0 # BS16
 53.81601E-3  60.14149E-3 -150.8049E+0 + BS16
 53.81601E-3 -300.0000E-3  180.0000E+0 # bottom border

     x2[m]       y2[m]     an2[deg] label
 56.00000E-3  67.85700E-3  45.00000E+0 # BS16
 450.0000E-3  67.85700E-3         0.0 # right border

OptoCad statistics:
  Number of optical components:  6
  Number of optical surfaces:  12
  Number of optical cavities:  0
  Number of input beams:  1
  Number of ray segments:  8
  Number of beams split off:  2
```



Building up the OB

Dummy TM mirrors will be used during alignment. They will have large diameter (15cm) so that their location and orientation can be measured with the CMM



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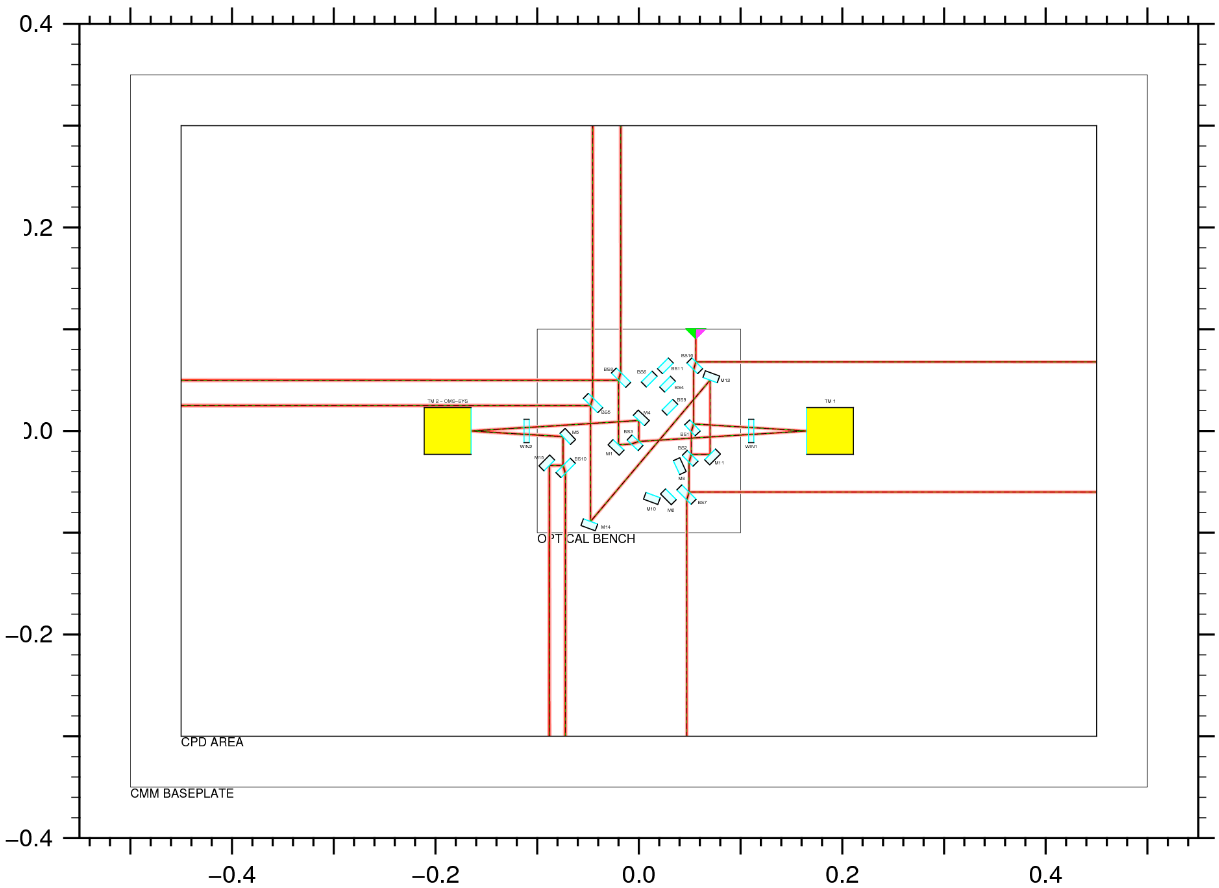
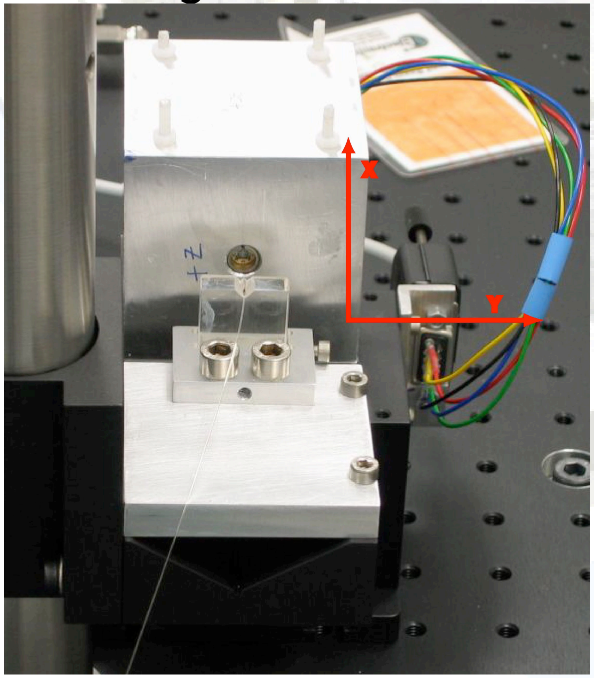
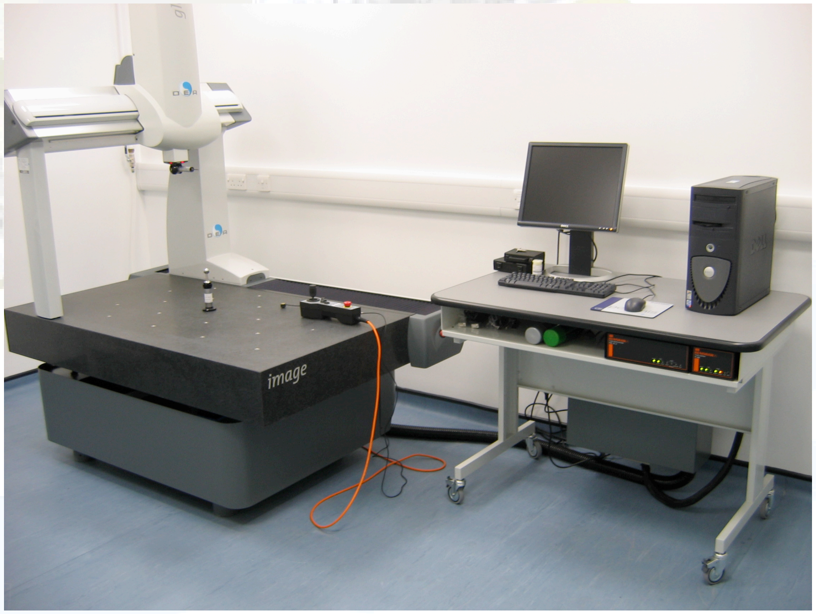


Beam position measurement

- Use a quadrant photodiode (QPD) as an optical target
- Mount the QPD in an aluminium block
- Calibrate the position of the QPD with respect to the block using a stable optical beam and a coordinate measurement machine (CMM)
- Once the QPD is calibrated, it can be positioned with respect to the bench using the CMM and the beam aligned to the QPD





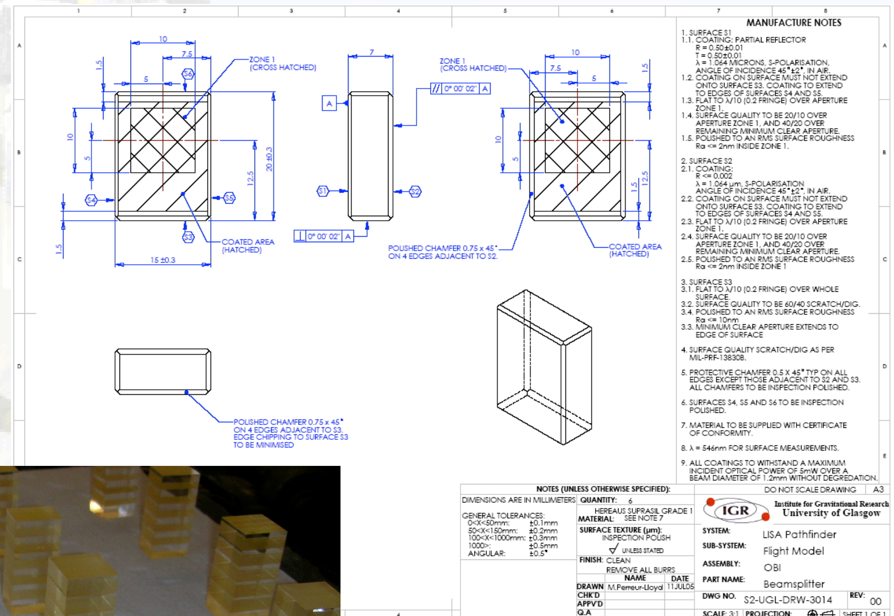
Alignment in z and _ (‘vertical’)

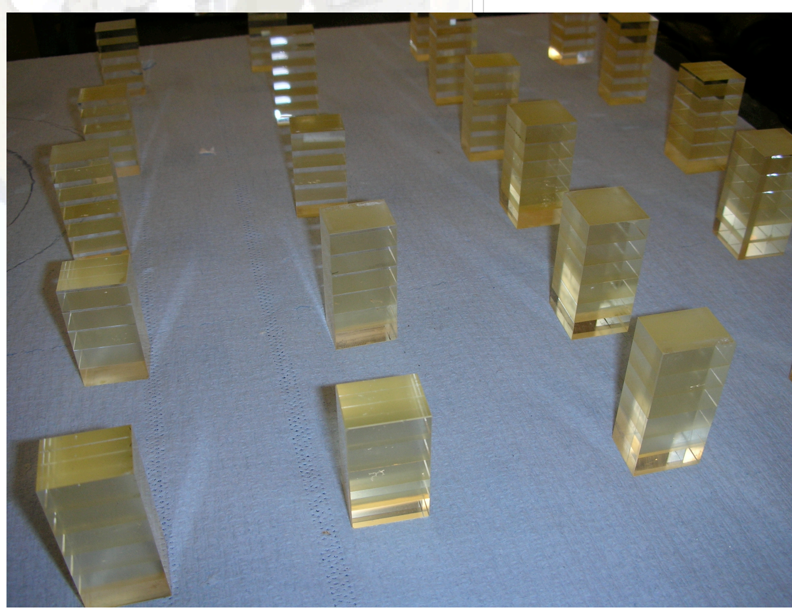
- ‘Vertical’ (out-of-plane) alignment depends on
  - FIOS alignment with respect to baseplate
  - Component manufacture
    - Mirror/beamsplitter component perpendicularity
    - Baseplate flatness
- An optical shop has demonstrated component perpendicularity at the sub-arcsecond level
- The baseplate bonding surface will be polished to _/4 over 100mm length scales
- The FIOS will be aligned using the adjustable bonding technique

Optical components

- Beamsplitter, beamcombiner and mirror designs completed and flight components currently being manufactured

Raw material





Mirrors and beamsplitters during manufacturing

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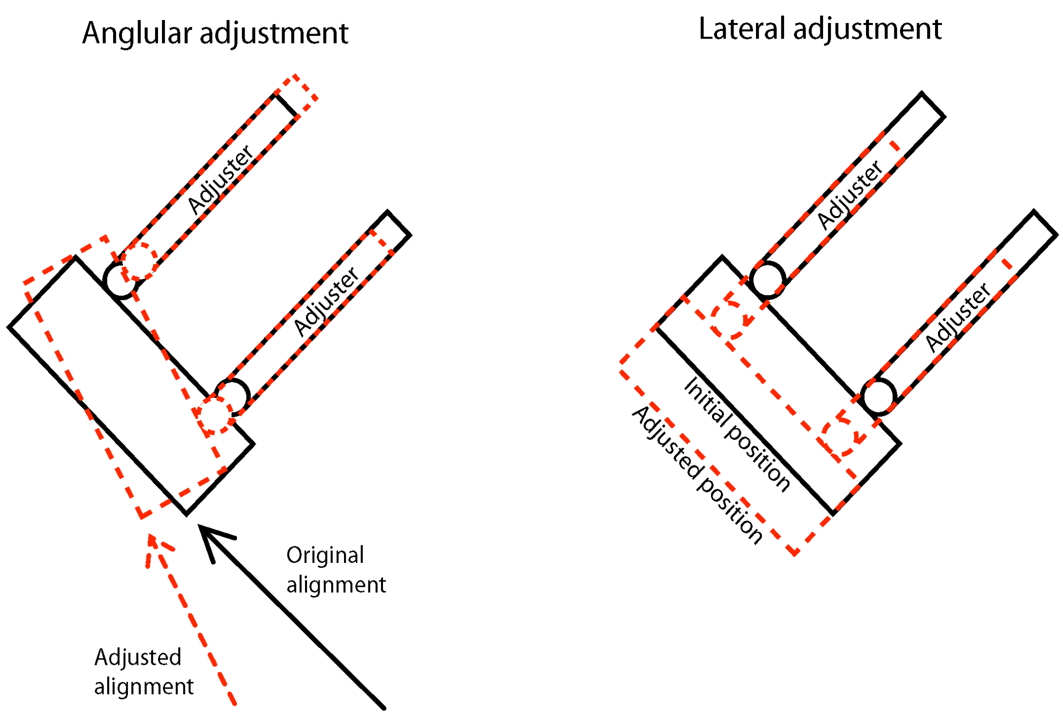
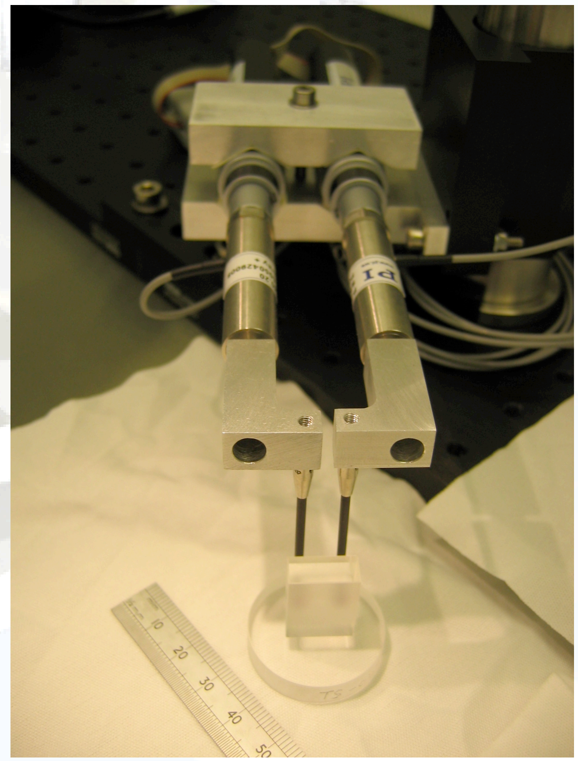
Alignment in y and _ ('horizontal')

- The precision alignment in the 'horizontal' comes from the positioning of the last optical component before the TM: BS1 and BS3
- Alignment of adjustable components on the OB uses two micropositioner fingers to adjust the remaining two degrees of freedom:



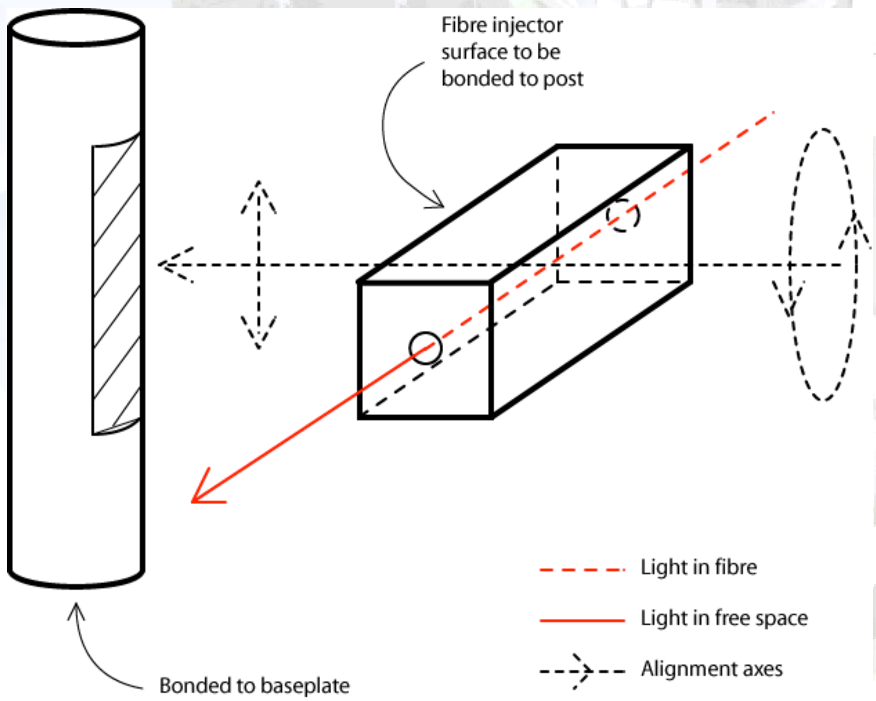
The positioners

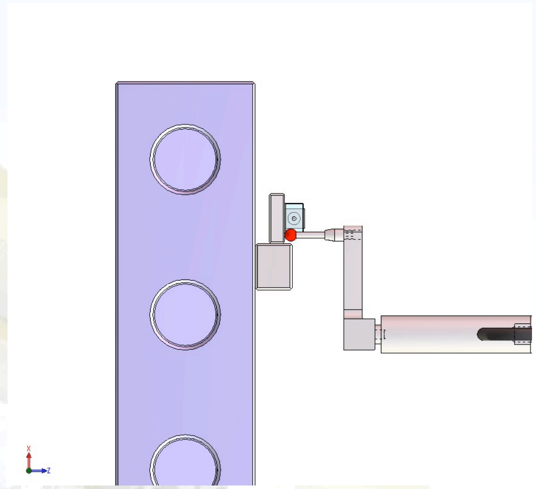
- The positioners each consist of a DC stepper section (large range, sub-micron resolution) and a PZT stage (small range, 10nm resolution)

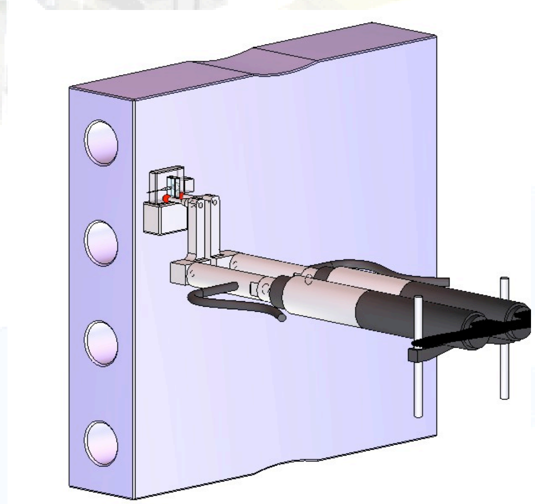


z and _: FIOS alignment

- The FIOS alignment principle and CAD drawings of the alignment







- Actuator movements of ~1_m will be required and this is achievable

Conclusions

- LTP optical bench answers many of the LISA optical bench questions
  - Construction
  - Stability
  - Interferometry
- Fibre injectors
  - Well studied solution
  - Construction underway
- Optical alignment
  - Precision required
  - Solution in place
  - Optical components being manufactured

Questions?